The Mathematics and Computation of Livestock Disease and Epidemics

DHS Advanced Scientific Computing Program

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ASC Gap Analysis Research Led to Funding for BKC to Develop a FMD Decision Support System

The livestock industry is a major target of bioterrorism

We performed a comprehensive review and gap analysis of the existing approaches to modeling and simulation of livestock epidemics

ASC research formulated the need for and possibility to develop a Decision Support System (DSS) for Evaluation and Planning of Response to Foot-and-Mouth disease epidemics

Proposal funded at $1.95M/yr; started April 2005

ASC is supporting the development of the DSS by research and development of new concepts, models and algorithms

The Livestock Industry is a Likely Target of Bioterrorism

- Known contagious human diseases have long incubation periods

	Pneum. Plague	Smallpox	Ebola	SARS	Marburg virus
Incub. period (days)	1- 6	7- 17	2- 21	2-14	5-10

- High rate of domestic travel and international travel create a high risk for world-wide export of human disease
- Livestock diseases have a larger potential for vast spread than human disease but a far more restricted international spread
- Livestock epidemics have a devastating economic effect

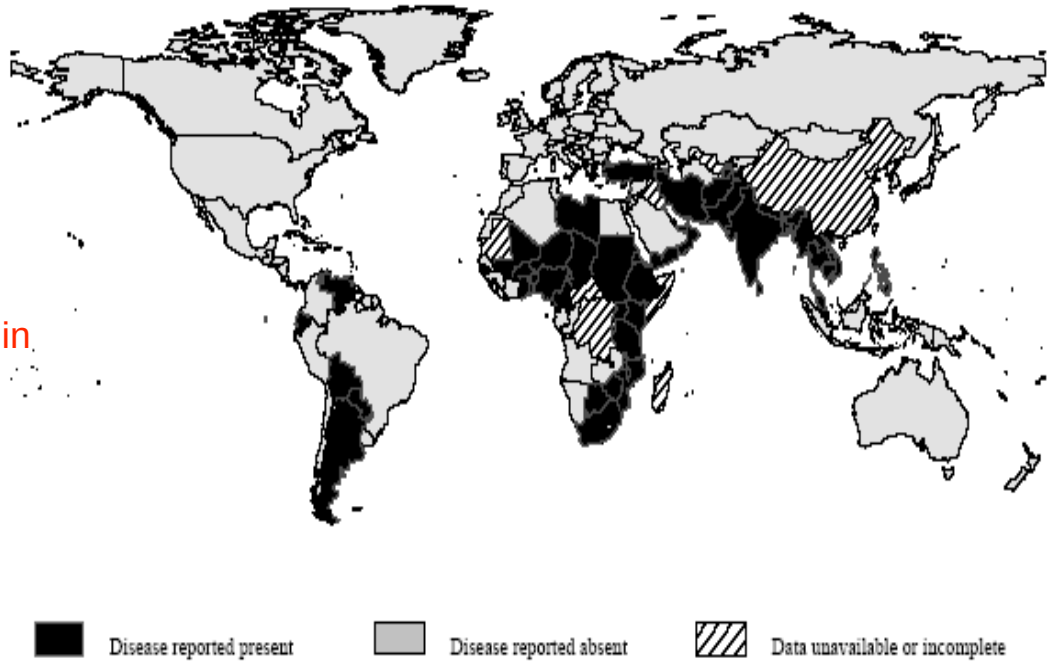
Foot and Mouth Disease is the Most Serious Agro-Terrorist Threat

- **FMD is one of the most contagious diseases known**

FMD virus very small, airborne,
adapted to replicate
in multiple species

Latent period 2-14 days
Subclinical period of 1-2 days; longer in sheep

High risks of indirect transmission



OIE Report 2003

Foot and Mouth Disease is the Most Serious Agro-Terrorist Threat

- **FMD epidemics have a devastating effect on the economy**

  2001 UK losses amounted to

  £3.1 billion to agriculture and the food chain;

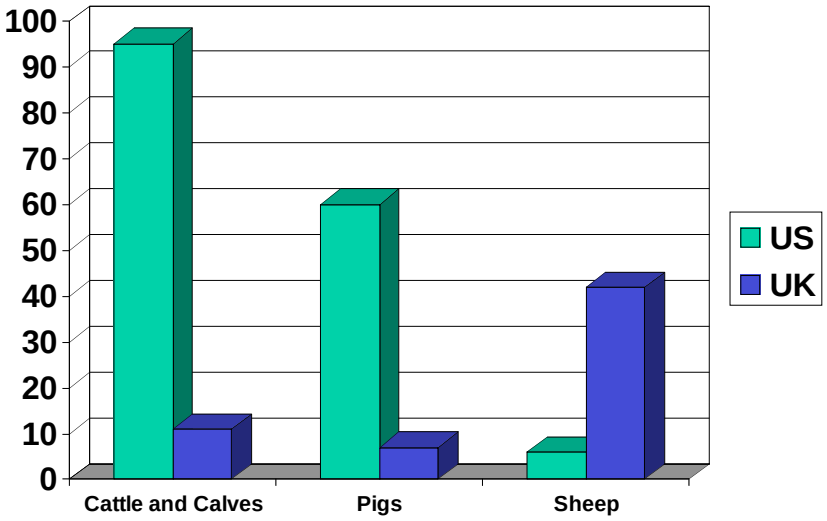
  £2.5 billion paid by the Government in animal compensation and clean-up

  4 million animals culled as part of disease control

  (The Royal Society, Infectious diseases in livestock, July 2002)

Foot and Mouth Disease is the Most Serious Agro-Terrorist Threat

The Scale of the US livestock Industry is orders of magnitude larger than UK's



US Farms 2,129,000
(USDA 2002 Data)

England farms 130 000
(2001 DEFRA Census Data)

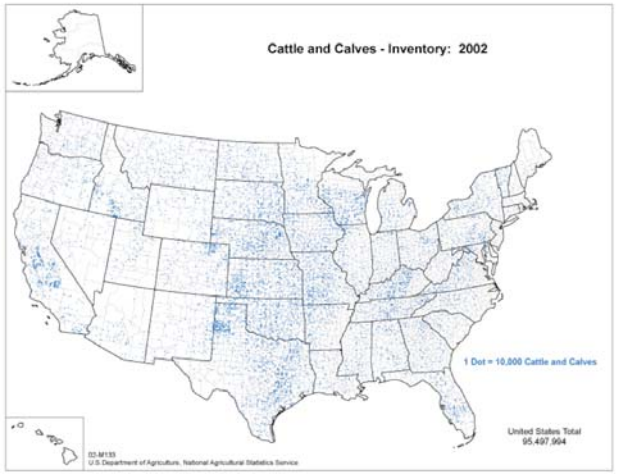
US Farm Sizes can be orders of magnitude larger

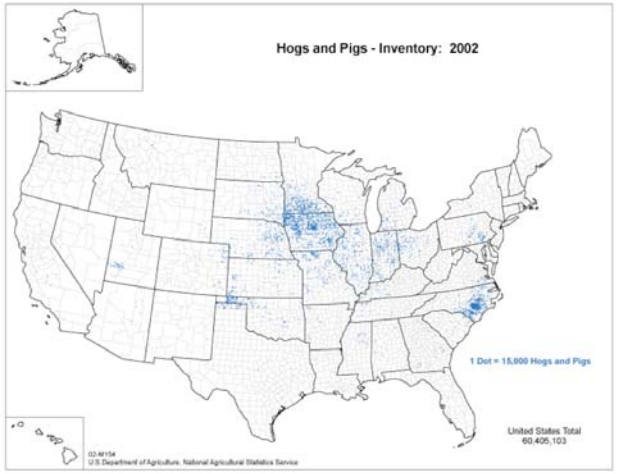
Data from:
Infectious diseases in livestock | **July 2002**|
USDA Census 2002

2001 DEFRA census

Analysis of the response to agroterrorism can be assessed by simulation modeling

- USDA Agriculture census provides a wide variety of county-based data (maps and tables)
- A variety of epidemic modeling efforts have been documented and publicized world-wide
- Modeling has a number of advantages: is harmless, provides insight, capability to experiment various strategies, can be used for education purposes



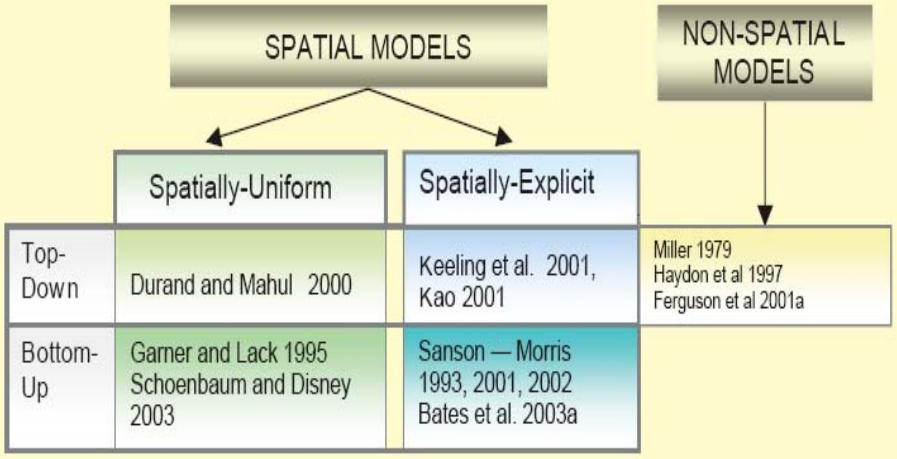


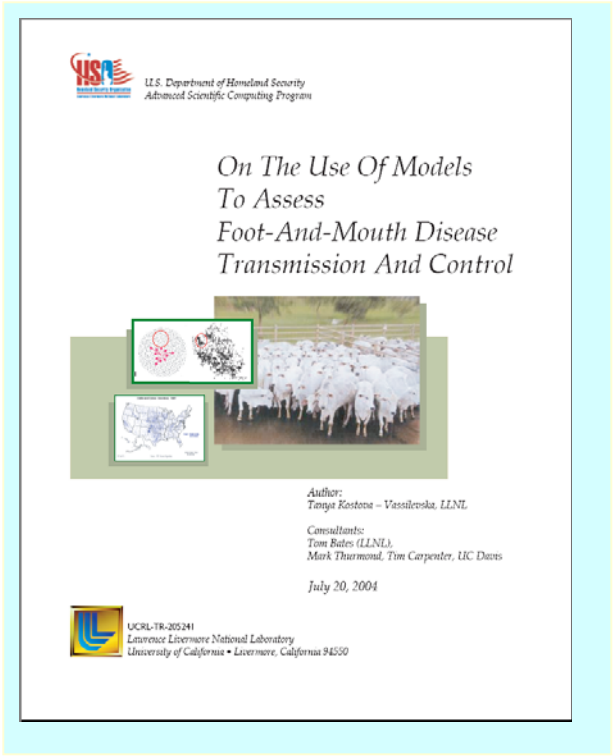
The ASC Program Funded a Gap Analysis Study of FMD Computational Models

About 80 papers reviewed

Models critically assessed and compared

Other, relevant non-modeling efforts reviewed





The Detailed Feature-by-Feature Comparison Revealed the Strengths and Weaknesses of Models

Table 1. The models and their features.

Model / Properties	Haydon et al. 1996	Miller 1979	Sanson 1993 Morris 2001, 2002	G&L 1995	Durand and Mahul 2000	Ferguson et al. 2001a, 2001b	Keeling et al. 2001	Kao 2001 2003	Bates et al. 2001, 2003a,b,c	Schoen-baum and Disney 2003
Type of model	DD T-D	DD T-D	SS B-U	SPS B-U	DD+SPS T-D	DODE T-D	SS T-D	SS T-D	SS B-U	SPS B-U
Time unit	1 day	1 week	1 day	1 week	Half week	1 day	1 day	1 day	1 day	1 day
Controls	N/A	S, CS	S,CS, V	S, CS, S+V	S,DS,V	CS, V	S,CS,DS, PS	S, CS, DS, V	S, DS, PS, V	S, DS, TS
Economic model	No	No	no	yes	yes	no	no	no	yes	yes
States	S, L, I, R	S, I, R, M	S, I, P, R, M	S, I, R, M	S,E,L,I,P, M,R	S,E,I,R, XY	S,L,I,R	S,I,R	S,L,I,P,R	S,L,I,M,R
TP depending on distance	N/A	No	yes	no	yes	yes	yes	yes	yes	yes
TP depending on herd/farm size	N/A	No	yes	no	yes	no	yes	yes	Partially (only two farm sizes considered)	no
TP depending on multiple species	N/A	No	yes	yes	yes	2001a no 2001b yes	yes	yes	yes	no
TP depending on time since infection	N/A	No	yes	no	no	2001a no 2001b yes	no	yes	Yes, via intraherd model	no
Species-specific transition rates	N/A	no	yes	no	no	no	no	no	yes	no
GIS used	N/A	no	yes	no	no	no	no	no	no	no
Intra-herd transmission	N/A	no	yes	no	yes	no	no	no	yes	no
Direct vs. indirect transmission	N/A	no	yes	no	yes	no	no	no	yes	yes
Airborne transmission	N/A	no	yes	no	no	no	no	no	no	yes
Markets (saleyards) present	N/A	no	yes	no	no	no	no	no	yes	no
Transmission depending on farm type (beef, dairy)	N/A	no	yes	no	no	no	no	no	yes	no
Network structure	N/A	no	implicit	no	no	yes	no	no	no	no

Abbreviations:
Model Types: DD- discrete deterministic state-transition model; DODE – deterministic ordinary equations model, SPS – stochastic spatially-uniform state-transition model, SS – spatially-explicit stochastic state transition model; T-D-"top-down", B-U-"bottom-up".
States: S- susceptible, I-infectious, M – immune, R – removed, XY– pairs of types X, Y where X, Y can take values S,E,I,R.
Controls: S(slaughter), CS (contact slaughter), DS (dangerous contacts), PS (pre-emptive slaughter), TS (traced contacts) , V(vaccination);
TP – transition probability

The Gap Analysis Justified the Need for a Decision Support System to Plan Response to FMD Epidemics

A DSS should incorporate

Databases

- spatial locations of US farms;
- types and sizes of US herds;
- actual pasture lands used;
- farm personnel;
- epidemic data (species - specific, strain - specific);
- economic data

Epidemic model(s)

Economic model(s)

Tools for analysis (statistical, sensitivity, optimization, visualization)

The Gap Analysis helped in Generating New DHS Funding to Develop the DSS

- Project started in April 2005
- Core team started preliminary work December 2004
- Partially supported by ASC program
- Prototype version of the epidemic model developed as a part of the

  LLNL Systems Study to Evaluate Defensive Architectures for an Intentional Introduction of FMD
- LLNL team works with USDA and the DHS Centers of Excellence to develop the model requirements and define the crucial data

ASC Identified Research Issues to be Addressed for the DSS Development Effort

- Improved methods to implement and analyze stochastic simulation models (SSM)

  - Algorithms to reduce the computational cost of large- scale SSM
  - Sensitivity analysis of SSM
  - Optimization techniques for SSM
  - Reducing the uncertainty by new modeling techniques
  - Qualitative understanding of the dynamics of stochastic models
  - Interpretation of the results

ASC identified research issues that need to be addressed for the DSS development effort

- Constructing aggregated (simple deterministic) models of infectious disease spread to use as a part of the DSS model

  Intra-herd transmission
  Epidemic spread along networks of farm groups

- Analysis of aggregated epidemic models

  Comparative analysis of the results of aggregated models will help in understanding the output of discrete stochastic simulations.
  This includes:
  Qualitative analysis
  Finding epidemic thresholds

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